NED University of Engineering & Technology, Karachi
M.Engg. (Mechatronics), Mid Term, Fall 2023 MC-511: Sensors & Actuators

December 31, 2023 Max Time: 2 Hours Max. Marks: 20

1. Robotic gripper (Shown in Figure 1) is widely used in manufacturing industry. Typically, it is used for pick and place robot (such as packaging and palletizing). You have to design a tactile sensor based robotic hand (actuator) with following capabilities: Low cost, ii) Temperature resistant, iii) minimum power consuming. *Provide at least two suitable combinations of selected models/designs. Justify the type of sensor that you are selecting/proposing for design from Table 1. Also, mention any tradeoffs (compromises), if exist.*
(4 Marks)

Figure 1

TABLE 1: Relative merits and demerits of various tactile sensor types [17].

Type	Merits	Demerits
Resistive	(i) Sensitive (ii) Low cost	(i) High power consumption (ii) Generally detect single contact point (iii) Lack of contact force measurement
Piezoresistive	(i) Low cost (ii) Good sensitivity (iii) Low noise (iv) Simple electronics	(i) Stiff and frail (ii) Nonlinear response (iii) Hysteresis (iv) Temperature sensitive
Tunnel effect	(i) Sensitive (ii) Physically flexible	(i) Nonlinear response
Capacitive	(i) Sensitive (ii) Low cost (iii) Availability of commercial A/D chips	(i) Hysteresis (ii) Complex electronics
Optical	(i) Physically flexible (ii) Sensitive (iii) Fast (iv) No interconnections	(i) Loss of light by micro bending chirping (ii) Power consumption (iii) Complex computations
Ultrasonic	(i) Fast dynamic response (ii) Good force resolution	(i) Limited utility at low frequency (ii) Complex electronics (iii) Temperature sensitive
Magnetic	(i) High sensitivity (ii) Good dynamic range (iii) No mechanical hysteresis (iv) Physical robustness	(i) Suffer from magnetic interference (ii) Complex computations (iii) Somewhat bulky (iv) Power consumption
Piezoelectric	(i) Dynamic response (ii) High bandwidth	(i) Temperature sensitive (ii) Not so robust electrical connection
Conductive rubber	(i) Physically flexible	(i) Mechanical hysteresis (ii) Nonlinear response

Q1 : Based on the information provided in the image, you are required to design a tactile sensor for a robotic gripper that is low cost, temperature resistant, and has minimum power consumption. The table in the image lists the merits and demerits of various tactile sensor types. To select at least two suitable combinations of sensor types from the table for this application, let's evaluate the options against the required capabilities:

1. *Resistive Sensors:*
   - Merits: Sensitive, Low cost.
   - Demerits: High power consumption, Generally detect single contact point, Lack of contact force measurement.

Resistive sensors could be a good option due to their sensitivity and low cost, which aligns with the requirement for a low-cost sensor. However, their high power consumption is a drawback as the requirement is for a sensor with minimum power consumption.

2. *Piezoresistive Sensors:*
- Merits: Low cost, Good sensitivity, Good noise immunity, Simple electronics.
- Demerits: Stiff and frail, Nonlinear response, Hysteresis, Temperature sensitive.

Piezoresistive sensors are also low-cost and have good sensitivity, but their temperature sensitivity makes them less suitable for applications requiring temperature resistance.

3. *Capacitive Sensors:*
- Merits: Sensitive, Physically flexible, Low cost, Availability of commercial A/D chips.
- Demerits: Hysteresis, Complex electronics.

Capacitive sensors are sensitive and low-cost, which satisfies two of the requirements. They are also physically flexible, which can be an advantage in a robotic gripper. The complexity of the electronics may be acceptable if the increased functionality is valued over simplicity.

4. *Piezoelectric Sensors:*
- Merits: Dynamic response, High bandwidth.
- Demerits: Physically flexible, Not so robust electrical connection, Mechanical hysteresis, Nonlinear response.

Piezoelectric sensors offer a good dynamic response and are physically flexible, but they may not be as cost-effective and are also temperature sensitive, which does not meet the temperature resistance requirement.

Given these considerations, the two most suitable types of sensors for this application would be:

First Choice: Capacitive Sensors
- They are sensitive and low-cost, meeting two crucial criteria.
- Their physical flexibility is beneficial for a gripper that needs to conform to different shapes.
- The demerit of complex electronics is a tradeoff for achieving the required sensitivity and flexibility.
- To mitigate the issue of hysteresis, careful design and calibration can be employed.

Second Choice: Resistive Sensors
- Despite their high power consumption, if the system can manage power effectively or if the sensors are only activated during short intervals, this demerit can be mitigated.
- Their sensitivity and low-cost nature make them an attractive option.
- The issue with single contact point detection and lack of force measurement might be acceptable compromises depending on the specificity of the tasks the gripper is performing.

In conclusion, capacitive sensors would likely be the primary choice due to their overall alignment with the requirements, and resistive sensors could be considered if power management solutions are implemented. The tradeoffs made here are in complexity of electronics for capacitive sensors and power consumption for resistive sensors. The final decision would also depend on the specific details of the robotic gripper's application and the environmental conditions it will operate in.

2. What is the utility of mechanism illustrated below? Does it qualify as a sensor or actuator?(2 Marks)

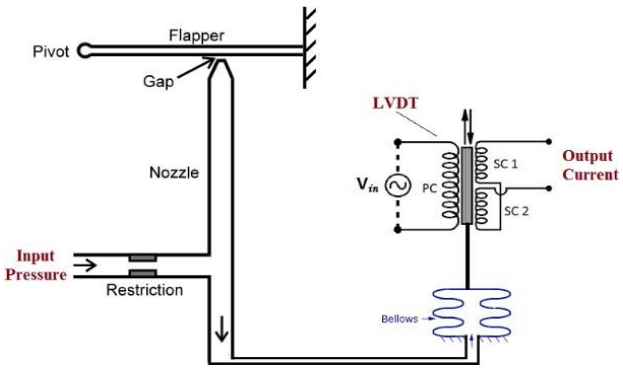

Figure 2

Q 2:The uploaded image, Figure 2, depicts a schematic diagram of a pneumatic control system. Here's how it works and its classification:

Utility:

- Input pressure is applied to the system, which then flows through a restriction to the nozzle.

- The flapper is positioned close to the nozzle. The distance between the nozzle and the flapper (the gap) can be varied.

- As the flapper moves closer to or further from the nozzle, it changes the back pressure in the nozzle.

- The bellows expand or contract in response to this back pressure, moving the flapper via the pivot.

- The Linear Variable Differential Transformer (LVDT) is connected to the flapper and converts the mechanical motion into an electrical signal.

- The electrical signal from the LVDT is conditioned by the control circuit to produce a standard output current, typically in the 4-20 mA range.

Classification:

- This system is a sensor, specifically a pressure sensor. The entire mechanism senses the input pressure changes and converts them into an electrical signal.

- The flapper-nozzle arrangement is part of the transducer that converts pressure input into a mechanical displacement.

- The LVDT is the actual sensor element that converts this mechanical displacement into a corresponding electrical signal, which is then used to indicate or control a process.

An actuator, in contrast, would be a device that takes an electrical signal and converts it into physical action, such as moving a valve. In this case, the diagram doesn't show a mechanism for creating movement based on an electrical signal but rather for sensing pressure changes and producing an electrical signal as a result. Therefore, this mechanism qualifies as a sensor.

Applications of such a system can include:

- Process control where accurate pressure measurements are crucial.

- Feedback systems in automated manufacturing to adjust for pressure variations.

- Safety systems to monitor and respond to pressure changes in a controlled environment.

3. Explain the function of arrangement shown in Figure 3. What could be the application of such system. (2 Marks)

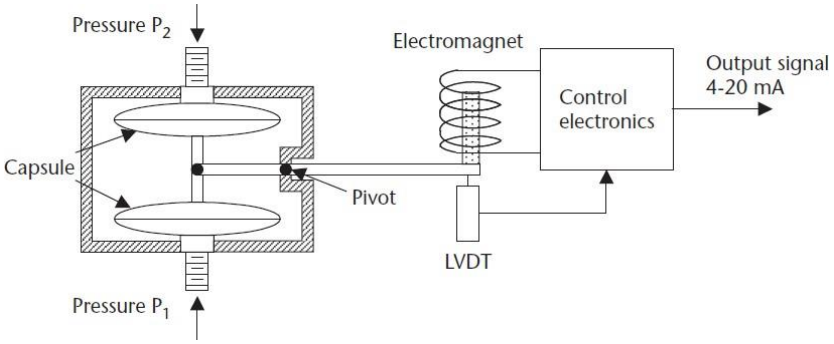

Figure 3

The image shows a diagram labeled Figure 3 with various components that appear to be part of a pressure measurement system. The system includes a capsule, a pivot, an electromagnet, a Linear Variable Differential Transformer (LVDT), control electronics, and an output signal. Here's a breakdown of the function and potential applications of this system:

Function:
- The capsule is a sensitive element that responds to differential pressure, with pressure \(P_1 \) applied to one side and pressure \(P_2 \) to the other.
- The difference in pressure causes the capsule to move, which in turn causes the pivot to move.
- The LVDT is a type of electrical transformer used for measuring linear displacement. It converts the mechanical motion of the pivot into an electrical signal.
- The electromagnet can be part of a feedback loop to maintain the position of the capsule or to counteract the movement caused by the pressure difference.
- The control electronics receive the electrical signal from the LVDT and process it to produce a standardized output signal, typically in the range of 4-20 mA, which is a common industry standard for transmitting analog signals over long distances.

Application:
This type of system could be used in various industrial and engineering applications where precise measurement of pressure difference is critical. The output signal of 4-20 mA is widely used in process control systems, meaning this device could easily interface with other industrial equipment, control systems, or data loggers.

Here are some specific applications:
- In HVAC systems to monitor differential air pressure across filters or in rooms.
- In the pharmaceutical industry, where clean rooms require precise pressure balancing.
- In the oil and gas industry for monitoring pressure differences in pipelines.
- In water treatment facilities to measure the pressure difference across membrane filters.

The standardized output signal allows for remote monitoring and control, which is essential in modern automated systems. The use of LVDTs also suggests that the system is designed for high-precision applications, as LVDTs are known for their accuracy, reliability, and stability.

4. Explain the function of mechanism shown in Figure 4. Is it a relative or absolute sensor? (2

Marks)

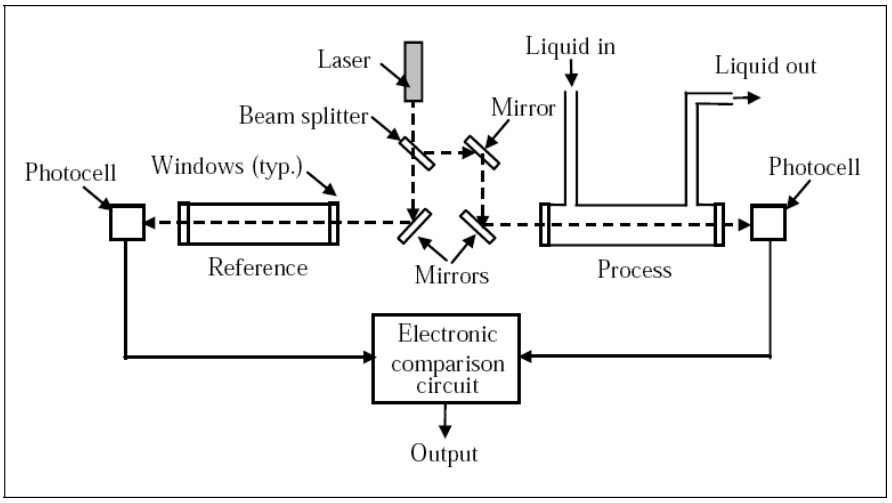

Figure 4

Q 4: The mechanism shown in the uploaded image, Figure 4, appears to be an optical sensor system that uses a laser and a beam splitter to direct light through a process (typically a fluid or gas) and onto photocells. Here's how it generally works:

1. A laser generates a coherent light beam that is directed towards a beam splitter.
2. The beam splitter divides the laser beam into two paths: one towards a reference path and the other towards the process path.
3. In the reference path, the light beam travels directly to a photocell through typical windows (which might be used to protect the beam from external interference).
4. In the process path, the light beam goes through the process medium (where liquid flows in and out) and is reflected back by mirrors towards another photocell.
5. The two photocells convert the light intensity they receive into electrical signals.
6. These signals are then sent to an electronic comparison circuit.
7. The comparison circuit analyzes the difference in intensity between the reference beam and the process beam.

The key to determining whether this is a relative or absolute sensor is in understanding what the sensor measures:

- An absolute sensor measures a quantity in fixed units and provides an exact reading. It does not need a reference point or comparison to give a meaningful reading.
- A relative sensor measures a quantity in comparison to a known reference or baseline measurement. It detects changes or differences from a normal or expected value.

Given this setup, the sensor appears to be a relative sensor because it is comparing the light intensity between the reference path and the process path. The presence of a reference path is a clear indication of a relative measurement system, as the sensor output is based on the relative difference between the process and the reference signal, rather than an absolute measure of light intensity.

This type of sensor could be used to detect changes in the process medium's characteristics, such as opacity, color, concentration of substances, or other optical properties that affect the intensity of light. The electronic comparison circuit can detect these changes by comparing the process signal to the reference signal, which remains constant. If the process medium changes in a way that affects light transmission (like increased turbidity), the comparison circuit will detect a difference between the two signals.

5. Compare the function, and the possible application of the mechanisms illustrated below: (4 Marks

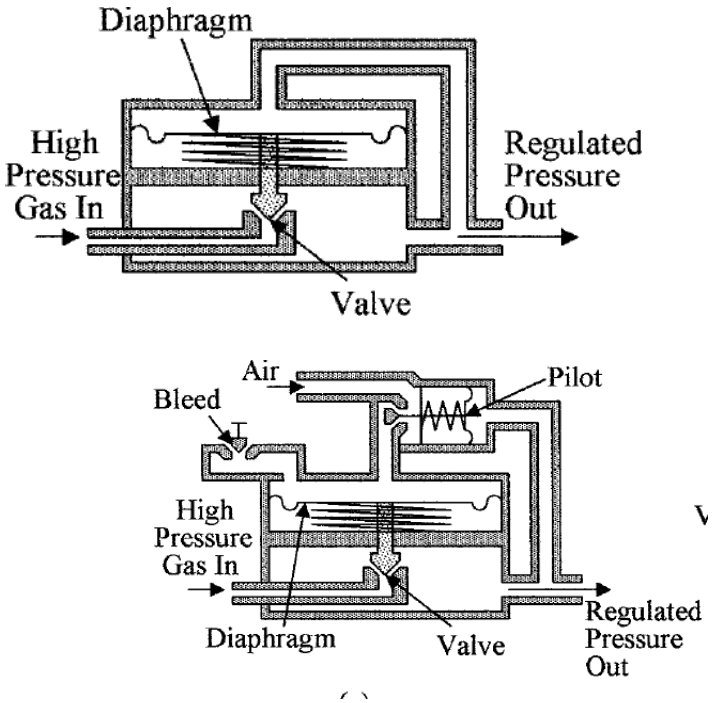

Figure 5

Q5 : The image you've uploaded shows two schematic diagrams of valve systems, labeled as Figure 5. These diagrams appear to represent pressure regulators, which are used to control the pressure of a fluid or gas to a desired value.

The top diagram shows a basic pressure regulator with a diaphragm that responds to the outlet pressure. The high-pressure gas enters the regulator, and the diaphragm adjusts the opening of the valve to maintain a constant regulated pressure on the outlet side.

The bottom diagram shows a more complex system with an additional component labeled "Pilot." This arrangement seems to be a pilot-operated regulator, where the pilot valve senses the outlet pressure and controls the main valve. This setup can provide more accurate pressure control, especially in systems where the flow rate varies significantly or where very precise pressure regulation is required.

These types of arrangements are used in various applications where controlled pressure is critical, such as in gas supply lines to burners, in pneumatic systems, and in fluid power systems. The specific applications can range from industrial settings, like chemical plants or refineries, to residential uses, such as in home heating systems.

The pilot-operated regulator (bottom diagram) typically allows for more stable control over a wider range of flows and reduces the "droop" in pressure that can occur in the basic regulator (top diagram) under varying flow conditions. It does this by using the pilot valve to more finely control the main valve, effectively decoupling the diaphragm movement from the direct flow of gas, allowing for a more precise response to pressure changes.

In terms of application, the choice between a direct-acting regulator (top diagram) and a pilot-operated regulator (bottom diagram) will depend on factors such as the required precision, the variability of flow rates, the size of the system, and cost considerations. Direct-acting regulators are simpler and less expensive but are typically used for lower-flow applications or where the precision of pressure control is not as critical. Pilot-operated regulators are more complex and expensive but are used in higher-flow applications or where precision is essential.

6. Select the best answer: (4 Marks)
   1) Any sensor is an energy converter. (True, False)
   2) Sensor output may be in the form of _____(amplitude, polarity, digital code, all of these).
   3) Sensors do not return to the same output value when the input stimulus is cycled due to _____(non-linearity, hysteresis, noise, saturation)

4) Absolute sensors are independent of the measurement conditions (True/False).
5) In active instruments, adjustment of the magnitude of the _____(internal, external) energy input allows much _____(lesser, greater) control.
6) The transfer function *mostly* shows the functional relationship between physical input signal and _____(mechanical, electrical) output signal.
7) A digital meter of 8 bit accuracy with a range of 10 Volts will have a resolution of _____ mV.
8) A zero order system has NULL time/decay constant (True, False)

These appear to be questions related to sensor technology and instrumentation. Let's go through them one by one:

1. *Any sensor is an energy converter.* (True, False)
Answer: True. Sensors typically convert physical phenomena (like temperature, pressure, light, etc.) into an electrical signal, thus acting as energy converters.

2. *Sensor output may be in the form of* (amplitude, polarity, digital code, all of these).
Answer: All of these. Sensor outputs can be in various forms including amplitude, polarity, and digital code, depending on the type of sensor and its application.

3. *Sensors do not return to the same output value when the input stimulus is cycled due to* (non-linearity, hysteresis, noise, saturation)
Answer: Hysteresis. This phenomenon occurs when the output of the sensor is dependent not only on the current input but also on the history of past inputs.

4. *Absolute sensors are independent of the measurement conditions* (True/False).
Answer: True. Absolute sensors measure a quantity in absolute terms, independent of other varying conditions.

5. In active instruments, adjustment of the magnitude of the...
(Seems like this question is incomplete.)

6. *The transfer function mostly shows the functional relationship between physical input signal and* (mechanical, electrical) output signal.
Answer: Electrical. The transfer function typically describes how the electrical output signal of a sensor responds to a physical input signal.

7. *A digital meter of 8 bit accuracy with a range of 10 Volts will have a resolution of* mV.
Answer: To calculate the resolution, divide the range by 2 raised to the number of bits. So, it would be $\frac{10\, \text{Volts}}{2^8} \approx 0.039\, \text{Volts} = 39\, \text{mV}$.

8. *A zero order system has NULL time/decay constant* (True, False)
Answer: True. A zero order system's response is instantaneous with respect to its input, so it has no time constant or decay constant.

7. An instrument is calibrated in an environment of 15 ºC as below:

y	13.1	26.2	39.3	52.4	65.5	78.6
x	5	10	15	20	25	30

However, the operating conditions changed from 15 ºC to 35 ºC in summer as below:

y	14.7	29.4	44.1	58.8	73.5	88.2
x	5	10	15	20	25	30

What is the new measurement sensitivity? Calculate the sensitivity drift in absolute and relative terms? (2 Marks)

Q7: The new measurement sensitivity at 35°C is 2.94 units per x.

The absolute sensitivity drift, which is the change in sensitivity from the original calibration at 15°C to the operating condition at 35°C, is 0.32 units per x.

The relative sensitivity drift, which is the absolute drift relative to the original sensitivity, is approximately 12.21%.